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1362902

(54) IMPROVEMENTS IN OR RELATING TO THE COOLING OF A GENERATING PLANT

(71) We, GESELLSCHAFT ZUR FORDERUNG DER FORSCHUNG AN DER EIDG. TECHN. HOCHSCHULE, of Zurich, Switzerland, a body Corporate organised and existing under the laws of Switzerland, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method of improving the removal of after heat in the event of an emergency shut-down of a gas-cooled nuclear reactor and to energy generating apparatus comprising a gas-cooled nuclear reactor arranged to operate in accordance with the method.

In the event of a serious breakdown in the operation of an energy generator plant which is fed by a nuclear reactor, for example for production of electric energy, the control rods of the reactor are very quickly guided between the fuel assemblies. The thermal output thus drops towards zero. Nuclear reactors, particularly those of the gas-cooled fast breeder type, produce for a long time, because of secondary radiation, a considerable output, the so-called after-heat, which cannot be checked by the control rods. Directly after the insertion of the control rods, this output amounts to about 15%, after 30 secs to about 5% and after a minute to about 3.5%, of the normal thermal output of the reactor. The fuel assemblies can be excessively heated by this very considerable heat output in large scale plants if the gas through-put provided for cooling should for some reason fail. Such a fault is particularly likely to occur if a break occurs in a tube directly at the entrance or exit of the reactor in the gas circuit.

If a less than fully integrated mode of construction has been selected for cost and operational reasons, the escaping gas then passes into the machine room and fills this more or less quickly. The pressure in this room increases whilst at the same time it reduces in the reactor to values which are inadequate to ensure a sufficient cooling of the reactor cores.

These processes can take place so quickly, and the heat capacity of the core, particularly of a fast bredeer, is so small that there is not enough time to switch on an emergency cooling blower. Such blowers must therefore be run continuously which constitutes a considerable operational disadvantage. It has therefore already been known to connect to a gas-cooled reactor of high capacity at least two, preferably three, closed cooling gas circuits in parallel each of which extends independently through a respective gas turbine and a respective compressor and back to the reactor, the gas turbine driving the compressor and an electric generator for producing electric energy. In the event of a break in the tube in one of these circuits and at the same time a possible breakdown in a second circuit, at least one gas turbine with a compressor continues operating whereby a gas supply through the reactor, however slight, is guaranteed.

The object of the present invention is to provide for improved removal of after-heat in the event of an emergency stoppage of a gas-cooled nuclear reactor of the last mentioned kind, in a comparatively simple and effective manner without any additional expensive means and with use of the machines available.

The invention accordingly provides a method for improving the removal of after heat in the event of an emergency shut-down of a gas-cooled nuclear reactor having at least two cooling circuits connected thereto and each extending independently from the reactor through respective gas turbine means, through at least one respective compressor, and back to the reactor, the turbine means being arranged to drive the compressor and a respective electric generator for the production of electricity, the method comprising the step of opening in each gas circuit a bypass in parallel with the gas turbine means so as

to reduce the generation of electrical energy and the flow resistance in the gas circuit in response to a decrease in gas pressure in the reactor, whereby the volume of gas per unit of time flowing through the reactor and required by the compressor is increased.

The gas turbine means of each circuit may comprise a high pressure turbine arranged to drive the compressor and connected in series with a low pressure turbine arranged to drive the generator, the method then including the steps of first opening a bypass in parallel with the low pressure gas turbine and then opening a second bypass in parallel with the two gas turbines, so that the speed of the high pressure gas turbine and of the compressor does not exceed a predetermined maximum value.

If a low pressure and a high pressure compressor are connected in series in each gas circuit, the method can include the step of opening a bypass in parallel with the high pressure compressor if the outlet to inlet pressure ratio of this compressor drops below a predetermined minimum value.

If a preheater is provided in each gas circuit for the gas supplied to the reactor, a bypass in parallel with the preheater can be opened in order to reduce the inlet temperature of the gas introduced into the reactor.

A pony motor which is coupled with the compressor or compressors and runs unpowered in normal operation, can be set in operation to provide an additional drive to the compressor and thereby increase the required volume of gas per unit of time in the event of an emergency shut-down of the reactor.

The invention also provides an energy generating apparatus comprising a gas-cooled nuclear reactor, at least two gas cooling circuits connected to the reactor, each gas circuit having associated therewith respective gas turbine means, a bypass connected in parallel with the gas turbine means a valve in the bypass which is closed in normal operation at least one respective compressor, and a respective electric generator for the production of electricity, the gas circuit extending from the reactor through the gas turbine means, through the compressor and back to the reactor, the gas turbine means being arranged to drive the compressor and the electric generator, at least one pressure gauge responsive to gas pressure in the reactor, and control means for actuating the valve in the bypass in each circuit in dependence on the pressure gauge in a manner such that the valve opens as soon as the gas pressure in the reactor drops below a predetermined minimmum value within a predetermined period of time.

The invention will be better understood from the following description and accompanying drawings. In the drawings:

Fig. 1 schematically shows a gas-cooled nuclear reactor plant with three parallel cooling circuits, each having a single-shaft gas-turbine/compressor generator group, of which only one circuit is shown in full; and

Fig. 2 similarly shows a like plant again with three cooling circuits of which only one is shown in full, each circuit having a high pressure and a low pressure gas turbine stage with separate shafts, of which the one drives the compressors and the other a generator.

According to Fig. 1, a gas-cooled nuclear reactor 1 has three inlets 2 and three outlets 3 for the gas for example helium which is used as a cooling medium and energy carrier. Each of the inlets 2 belongs to a closed gas circuit including a respective one of the outlets 3. All three gas circuits are identical and operate in parallel. Within the reactor, there is no separation between the gas circuits. Thus, the gas circuits are independent outside of the reactor only. For simplicity, only one gas circuit is illustrated in Fig. 1 in full, and is described in detail below.

The reactor outlet 3 of this gas circuit is connected to the inlet 5 of a gas turbine 6 which drives a shaft 4. The low pressure gas leaving the gas turbine 6 is fed via a pipe 7 through the primary path of a heat exchanger 8 and thne through a cooler 9 to the inlet of a low pressure compressor 10. The gas is compressed in the compressor 10 to an intermediate pressure and is then passed through an intermediate cooler 11 to the inlet of a high pressure compressor 12. The gas, now compressed to the final pressure, is passed from the output of the high pressure compressor 12 through the second path of the heat exchanger 8 which serves as the preheater to the inlet 2 of the reactor 1. The two compressors 10 and 12 are drivingly connected with the shaft 4 of the gas turbine 6. Furthermore, an electric generator 19 for producing electric energy, and also a pony motor 22 for starting up the group of machines 6, 10, 12, are coupled with the shaft 4 when the apparatus is to be set in operation.

The design of the generator plant described so far with reference to Figure 1 is in itself known and in accordance with the invention the following additional arrangements are provided.

A bypass connection 14 branches off from a point 13 between the outlet 3 of the reactor and the inlet 5 of the gas turbine 6, extends through a cooler 15 and a valve 16, and opens into the gas circuit again upstream of the cooler 9. The bypass connection 14 is thus connected in parallel with the gas turbine 6 and the primary path of the heat exchanger 8. In the reactor 1 a pressure gauge 17 is provided which responds to the gas pressure prevailing in the reactor and is able to determine and signal any sudden undue drop in the pressure. The pressure gauge 17 is operatively connected to the

valve 16 by way of a control means 18 so as to be able to operate the valve, as will be explained below. The shaft 4 is connected with a governor or sensing element 20 responsive to the rotational speed of the shaft and which is likewise operatively connected to the valve 16 by means of an additional control means 21 so as to actuate the valve, as will also be described below.

A second bypass connection 23 which contains a valve 24 is connected in parallel with the high pressure compressor 12. Control means 25 are provided which respond to the pressure ratio between the inlet and outlet of the high pressure compressor 12 and are in operative connection with the valve 24, so as to be able to actuate said valve, as will again be described below.

A third bypass connection 26 which contains a valve 27 is connected in parallel with the secondary path of the heat exchanger 8. In the reactor is located a gauge 28 which responds to the outlet temperature or if required to the pressure of the gas and which is in operative connection with the valve 27 by way of a control means 29, in order to be able to actuate this valve.

The method of operation of the energy generator plant of Figure 1 is described below.

During undisturbed normal operation, the valves 16, 24 and 27 are closed. The gas which is used as the cooling medium and energy carrier issues from the outlets 3 of the nuclear reactor 1 at a temperature of for example 650°C and a pressure of for example 82 bars. In each of the three parallel gas circuits, the gas is passed to the inlet of the gas turbine 6 in which it expands and thereby produces the mechanical energy for driving the generator 19 and the two compressors 10 and 12. The pony motor 22 is switched off and runs unenergised. The gas leaving the gas turbine 6 pases through the heat exchanger 8 and the cooler 9 to the inlet of the low pressure compressor 10 which compresses the gas to the intermediate pressure. The gas is then return-cooled in the intermediate cooler 11 so that afterwards it can be brought with a lower power input in the high pressure compressor 12 to the final pressure of for example 90 bars. The gas which is thus compressed is, for improving the efficiency of the circuit, preheated in the heat exchanger 8 to a temperature of for example 315°C and then passed back to the reactor 1 via the revelant inlet 2 thereof, the gas circuit being thus completed.

If a break occurs in the pipe of one the three parallel gas circuits for example at the point 30, the gas pressure in the whole system, but particularly in the reactor 1 begins to drop immediately. In the event of a sudden undue drop of the pressure, a signal is generated by the pressure gauge 17 which triggers off an emergency stoppage of the reactor that is an immediate descent of the control rods and at the same time automatically produces by means of the control means 18 a partial opening of the valve 16 in the bypass connection 14 of each gas circuit. A flow route is thereby opened in parallel with the gas turbine 6 and primary path of the heat exchanger 8 in each gas circuit and thus the flow resistance of the gas in the remaining part of the gas circuit is reduced. Because of the characteristics of the compressors 10 and 12 the volume of gas supplied by the compressors and flowing to the reactor 1 increases per unit time so that the undamaged gas circuits exert an increased cooling effect on the reactor in order to make up sufficiently for the full or partial failure of the damaged circuit. The opening of the valve 16 in the bypass 14 results in a reduction in the generation of electric energy by the generator 19 because less gas than normal flows through the gas turbine 6.

In the event that the generator 19 remains connected to a current network which is also fed by a different power unit the generator is driven like a motor from the electric circuit after the reduction in output of the gas turbine 6 so that the speed of rotation of the compressors 10 and 12 is not reduced. If however the generators 19 are disconnected from the electric power lines at the moment the reactor is shut-down, the turbine 6 of each gas circuit first develops more mechanical energy than is consumed by the compressors 10 and 12. Consequently the speed of rotation of the shaft 4 begins to increase, whereupon the speed sensing element 20, by way of the control means 21, opens the valve 16 in each bypass 14 to a greater extent than is caused by control means 18 in response to the pressure gauge 17. The result is that less gas flows through the turbine 6 of each gas circuit and the rotational speed of the turbine is thus reduce until approximately the normal operation speed is reached. With the valve 16 opened further, the flow resistance in the gas circuit is reduced and the volume of gas supplied by the compressors 10, 12 through the reactor 1 per unit of time is increased, so that an increased cooling of the reactor results. The cooler 15 in the bypass connection 14 reduces the temperature of the gas passing through the valve 16 in order to prevent damage thereto.

If the generators 19 have been disconnected from the electric power lines, the pony motor 22 associated with each gas circuit can be switched on in order to further increase the cooling gas flow through the reactor 3. The switched-on pony motor 22 tends to increase the rotational speed of the shaft 4, whereupon the speed sensing element 20, by way of the control means 21, again causes the valve 16 in each bypass connection 14 to open further.

This results in a lower flow resistance and a corresponding increase in the volume of gas supplied by the compressors 10, 12 through the reactor per unit of time. The wider opening of the valve 16 in each bypass connection 14 reduces the gas flow through the associated turbine 6 so that the speed of rotation is reduced accordingly to approximately the speed of normal operation. The described switching on of the pony motors 22 can be arranged to take place in response to the sensing by the temperature gauge 28 in the reactor 1 of a gas outlet temperature exceeding a predetermined maximum value.

With an increasing volume of gas supplied to the high pressure compressor 12 per unit of time, as occurs when the valve 16 is opened wide as described above, the high pressure compressor 12 becomes less and less able to effect further compression of the gas, because the gas pressure cross-sectional area of the high pressure compressor is much smaller than that of the low pressure compressor, as the high pressure compressor is dimensioned to operate best with a small volume of compressed incoming gas, not with a great volume of gas, in contrary to the low pressure compressor. As soon as the gas travels through the high pressure compressor with a velocity exceeding about 1.5 times the normal gas inlet velocity, the high pressure compressor can no longer effect a further increase in the gas pressure, and tends to act as a flow resistor when the outlet to inlet pressure ratio approaches 1 or becomes lower than 1. In order to avoid this disadvantageous effect of having a flow resistance in the gas flow through the reactor 1, the valve 24 in the bypass connection 23, in parallel with the high pressure compressor 12, is opened by the control means 25 as soon as the outlet to inlet pressure ratio of the high pressure compressor drops to a predetermined minimum value.

A further intensive cooling action is achieved by opening the valve 27 in the bypass connection 26 parallel to the secondary path of the heat exchanger 8, whereby the preheating of the gas which takes place during normal operation before it enters the reactor 1, is discontinued so that the gas flows into the reactor at a low temperature. The valve 27 is opened by the control means 29 in dependence on the gauge 28 when the other cooling of the reactor is insufficient.

The energy generator plant embodying the invention and illustrated in Figure 2 differs from that described above only in that instead of a single gas turbine each of the three parallel gas circuits, of which only one is shown in full, has two gas turbines namely a high pressure gas turbine 61 and a low pressure gas turbine 62 connected in series and with separate output shafts. The shaft 41 of the high pressure gas turbine 61 is drivingly connected to the compressors 10 and 12, whilst the shaft 42 of the low pressure gas turbine 62 is drivingly connected tó the generator 19 for producing the electric energy which is to be released. The pony motor 22 is coupled with the shaft 41 of the compressor group.

A bypass 141 which is arranged in parallel with the low pressure gas turbine 62 contains a valve 161 which can be actuated by the control means 18 mentioned in connection with Figure 1 in dependence on the pressure gauge 17 arranged in the reactor 1. The shaft 42 of the low pressure gas turbine 62 is connected with a sensing element 201 which responds to the speed of rotation and is likewise operatively connected by a control means 211 with the valve 161 so as to be able to actuate this valve, as will be explained below.

A second bypass 142 which branches off from a point 13 between the reactor output 3 and the input 5 of the high pressure gas turbine 61 of each gas circuit, passes back to the relevant gas circuit by way of a cooler 152 and a valve 162 upstream of the cooler 9. The second bypass 142 consequently runs parallel to the two gas turbines 61 and 62 as well as to the primary path of the heat exchanger 8. A second speed responsive element 202 is connected with the shaft 41 of the high pressure gas turbine 61 which drives the compressors 10 and 12, and is in operative connection with the valve 162 by way of control means 212 so as to be able to actuate this valve, as will be explained below.

The remaining features of the plant of Figure 2 are identical with those described in Figure 1.

The operating method of the energy generator plant according to Figure 2 is normally basically the same as in the first embodiment. The valves 161, 162, 24 and 27 are then closed. If a break in the tube occurs in one of the parallel gas circuits for example at the point 30, the gas pressure in the reactor 1 drops. The pressure gauge 17 in response to the fall in pressure in the reactor immediately switches off the reactor and causes the valve 161 in bypass 141 to be immediately completely opened by the control means 18. The volume of gas passing through the low pressure gas turbine is drastically reduced, so that correspondingly less mechanical output is supplied to the generator 19. On opening the valve 161 the flow resistance of the gas is reduced at the outlet of the high pressure gas turbine 61, which results in an intensive acceleration of the high pressure gas turbine and of the compressors 10 and 12. The sensing element 202 responsive to the speed of rotation of the shaft 41 thus effects, through the control means 212, a partial opening of the valve 162 in the bypass 142 whereby a shunt is opened in parallel with both the gas turbines 61 and 62 so that the gas

throughput is also reduced by the high pressure gas turbine 61 which counteracts an increase in the speed of the shaft 41 above a predetermined value. The valve 162 is automatically adjusted by means of the sensing element 202 and the control means 212 so that a balance arises between the output supplied to the high pressure gas turbine 61 and the output assumed by the compressors 10 and 12 with a slightly increased speed of the shaft 41. The flow resistance in the gas circuit is now reduced partly by the open bypass 141 and partly by the second open bypass 142 so that the compressors 10 and 12 supply an increased volume of gas per unit time to the reactor 1, whereby the reduction of the cooling effect caused by the break in the tube 30 is adequately compensated. The output, more of which is supplied to the high pressure gas turbine 61, as compared with normal operation, is raised by the increased delivery of the compressors 10 and 12.

An intensive cooling action can be achieved by switching on the pony motor 22 which runs disconnected during normal operation. If the pony motor 22 is set in operation, it endeavours to increase the speed of rotation of the shaft 41 which however, causes the sensing element 202, which responds to this speed of rotation, to further open the valve 161 by means of the control means 212, in order to counteract the increase in speed. This further opening of the valve 162 results in an additional drop in the flow resistance and thus a further increase in the volume of gas passing through the reactor per unit time. Thorough investigations have shown that a greater increase in the volume supplied can be achieved in the manner described that is by further opening the valve 162 by means of the element 202 and control means 212 than by merely increasing the speed of the compressors 10 and 12 with the aid of the pony motor 22. The gas flowing through the second bypass 141 is cooled by the cooler 152 so that the valve 162 suffers no damage through excess heating.

As in the embodiment of Figure 1, the cooling of the reactor 1 can if necessary be still further intensified by opening the valves 24 and 27.

If during normal operation, or in the case of emergency before the opening the valve 161 by the pressure gauge 17 and the control means 18, the electric generator 19 is for some reason disconnected from the power network so that consequently no more is consumed, the speed of the now unloaded low pressure gas turbine 62 rapidly increases. In this case, the valve 161 becomes opened by the sensing element 201 which responds to the speed of the shaft 42 and by the control means 211, as soon as a predetermined maximum value of the speed is exceeded. The gas flow is considerably reduced by the low-pressure gas turbine 62 and thus keeps the group of machines 19, 62 from operation at unduly high speeds.

WHAT WE CLAIM IS:—

1. A method of improving the removal of after heat in the event of an emergency shut-down of a gas-cooled nuclear reactor having at least two cooling circuits connected thereto and each extending independently from the reactor through respective gas turbine means, through at least one respective compressor, and back to the reactor, the turbine means being arranged to drive the compressor and a respective electric generator for the production of electricity, the method comprising the step of opening in each gas circuit a bypass in parallel with the gas turbine means so as to reduce the generation of electrical energy and the flow resistance in the gas circuit in response to a decrease in gas pressure in the reactor, whereby the volume of gas per unit of time flowing through the reactor and required by the compressor is increased.

2. A method as claimed in claim 1, the gas turbine means comprising a high pressure turbine arranged to drive the compressor and connected in series with a low pressure turbine arranged to drive the generator, the method including the steps of first opening a bypass in parallel with the low pressure gas turbine and then opening a second bypass in parallel with the two gas turbines, so that the speed of the high pressure gas turbine and of the compressor does not exceed a predetermined maximum value.

3. A method as claimed in claim 1 or 2, a low pressure and a high pressure compressor being connected in series in each gas circuit, the method including the step of opening a by pass in parallel with the high pressure compressor if the outlet to the inlet pressure ratio of this compressor drops below a predetermined minimum value.

4. A method as claimed in claim 1, 2 or 3, a preheater for the gas supplied to the reactor being provided in each gas circuit, the method including the step of opening a bypass in parallel with the preheater.

5. A method as claimed in claim 1, 2, 3 or 4 including the step of setting in operation a pony motor coupled to the compressor or compressors of each circuit in the event of an emergency shut down of the reactor.

6. Energy generating apparatus comprising a gas-cooled nuclear reactor, at least two gas cooling circuits connected to the reactor, each gas circuit having associated therewith respective gas turbine means, a bypass connected in parallel with the gas turbine means, a valve in the bypass which is closed in normal operation at least one respective compressor, and a respective electric generator for the

production of electricity, the gas circuit extending from the reactor through the gas turbine means, through the compressor and back to the reactor, the gas turbine means being arranged to drive the compressor and the electric generator, at least one pressure gauge responsive to gas pressure in the reactor, and control means for actuating the valve in the bypass of each circuit in dependence on the pressure gauge in a manner such that the valve opens as soon as the gas pressure in the reactor drops below a predetermined minimum value within a predetermined period of time.

7. Apparatus as claimed in claim 6 having a gas cooling device positioned in each bypass in front of the valve.

8. Apparatus as claimed in claim 6 or 7 in which the shaft of the compressor associated with each gas circuit is connected to a rotational speed sensor, and additional control means are provided for operating the valve in each bypass in dependence on a signal of the associated speed sensor, the valve in each bypass being operated in a manner such that the speed of the compressor does not exceed a predetermined maximum value.

9. Apparatus as claimed in claim 6, 7, or 8 in which the gas turbine means of each gas circuit comprises a high pressure turbine arranged to drive the compressor and a low pressure turbine arranged to drive the generator, in which the bypass in each gas circuit is connected in parallel with the low pressure gas turbine, in each gas circuit includes a second bypass connected between the gas output of the reactor and the input of the compressor, the second bypass including a valve which is closed during normal operation. in which the shaft of the compressor is associated with an element which responds to the speed of rotation thereof, and in which control means are provided for actuating the valve in the second bypass in dependence on the speed responsive element in a manner such that the valve is actuated to such an extent that the speed of rotation of the compressor does not exceed a predetermined value.

10. Apparatus as claimed in claim 9 having a gas cooling device positioned in the second bypass in front of the valve.

11. Apparatus as claimed in claim 9 in which the shaft of the low pressure gas turbine is associated with an element responsive to the speed of rotation thereof and in which additional control means are provided for actuating the valve in the bypass in parallel with the low pressure gas turbine in dependence on the speed responsive element in a manner such that the valve is actuated to such an extent that the speed of rotation of the low pressure gas turbine does not exceed a predetermined maximum value.

12. Apparatus as claimed in any one of claims 6 to 11 in which each gas circuit includes a low pressure and a high pressure compressor connected in series and having a common driving shaft, in which a bypass is connected in parallel with the high pressure compressor and contains a valve which is closed in normal operation, and in which control means are provided for opening the valve in the event of a drop in the pressure ratio between the inlet and outlet of the high pressure compressor.

13. Apparatus as claimed in any one of claims 6 to 12 in which the gas leaving the gas turbine means of each circuit is arranged to pass through the primary path of a heat exchanger serving as the preheater for the gas passing to the reactor, the secondary path of the heat exchanger extending in the circuit between the gas outlet of the compressor or compressors and the gas inlet of the reactor, a bypass being connected in parallel with the secondary path of the heat exchanger and including a valve which is closed in normal operation, and control means being provided such that the valve is opened when the gas outlet temperature of the reactor exceeds a predetermined maximum value.

14. Apparatus as claimed in any one of claims 6 to 13 in which the or each compressor is coupled with a pony motor and in which control means are provided and for starting each pony motor when the gas outlet temperature of the reactor exceeds a predetermined maximum value.

15. Apparatus as claimed in any one of claims 6 to 14 having a single pressure gauge associated with both or all circuits.

16. Apparatus as claimed in any one of claims 6 to 14 having a respective pressure gauge associated with each circuit.

17. A method of improving the removal of after heat in the event of an emergency shut-down of a gas-cooled nuclear reactor substantially as herein described with reference to Fig. 1 or Fig. 2 of the accompanying drawings.

18. Energy generating apparatus including a gas-cooled nuclear reactor, the apparatus being substantially as herein described with reference to Fig. 1 or Fig. 2 of the accompanying drawings.

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1362902 COMPLETE SPECIFICATION

2 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheet 1

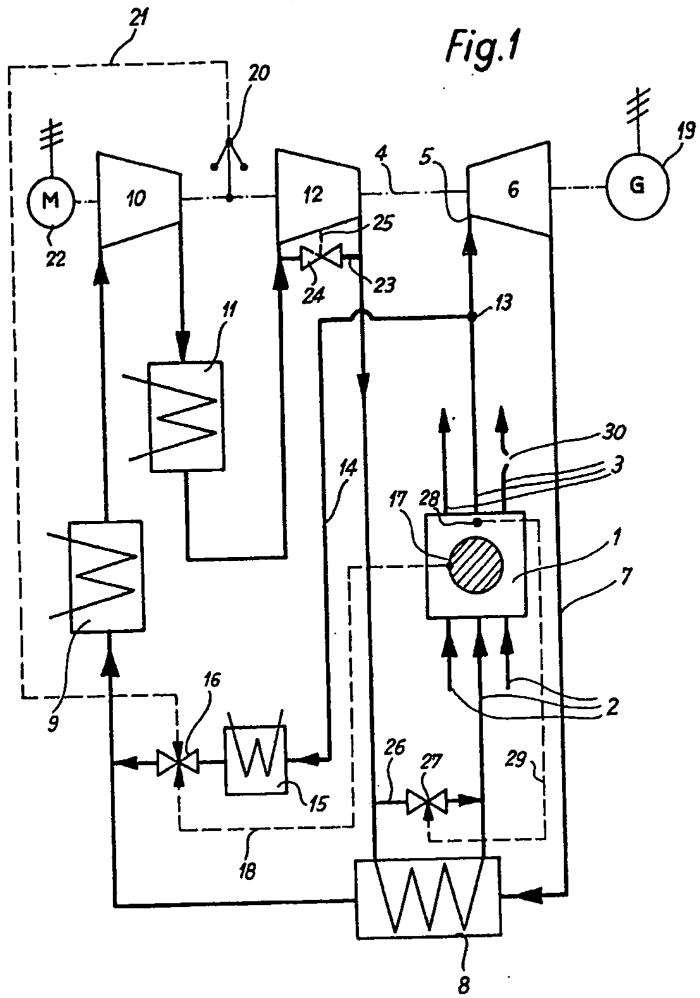
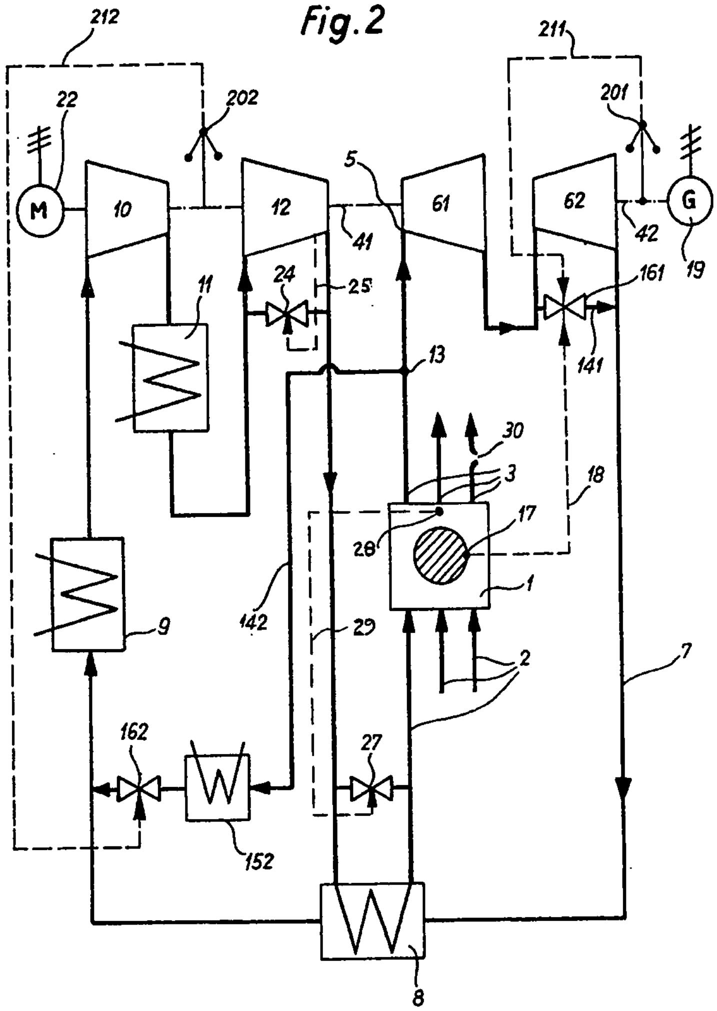


Fig. 2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